

A SLED TEST PROCEDURE PROPOSAL TO EVALUATE THE RISK OF NECK INJURY IN LOW SPEED REAR IMPACTS USING A NEW NECK INJURY CRITERION (NIC)

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ABSTRACT

Today's cars do not sufficiently prevent neck injuries in rear end impacts. So called whiplash injuries are often sustained at low velocities. According to Swedish road casualty statistics, the risk for whiplash injuries increases dramatically with the velocity change (Δv) of the impacted car in the interval between 10-20 km/h. During recent years, much progress has been made in research concerning this issue. This includes new findings from injury statistics, better knowledge of injury mechanisms (even if they are not yet fully understood) and development of suitable rear impact dummies.

This paper describes a new sled test procedure involving two levels of rear impact severity. In the proposed procedure, a new neck injury criterion (NIC) which is a measure of the effect of violence to the neck, is used to evaluate the level of neck protection.

Seats, from two cars with different neck injury-risk rating (according to Swedish statistics), have been tested according to the new procedure and compared with a new seat concept. The results indicate that a seat back with a low yielding limit has a lower risk of neck injury, which is reflected in lower NIC-values.

INTRODUCTION

When designing car seats to prevent injuries in high Δv rear-end collisions (Δv above 25 km/h and 10 g in crash pulse), there already exist sled test procedures including risk evaluation criteria (Viano, 1994). For this level of severity most researchers agree that neck hyper extension and occupant ramping up the seat back (with the potential for secondary impact of the occupant with the rear seat and the rear window) must be avoided. By improving the head rest and stiffening the seat, the occupant may be protected from life threatening injuries. On the other hand, AIS 1 classified neck injuries, sustained mostly at low speed rear-end collisions (Eichberger et al. 1996, Parkin et al. 1995) have been given increased

attention over the last ten years. According to Nygren et al. (1984), Lundell et al. (1998) and v Kock et al. (1995, 1996), these injuries are by far the most common injury type in rear end impacts and cause long term disability in 1 out of 10 injury cases (Nygren, 1984). Despite these facts, there are no established test methods nor evaluation criteria for low speed rear impacts. A reasonable requirement for a test procedure, evaluating disabling neck injuries in these impacts, would be the ability to discriminate between circumstances with different injury risk (Jakobsson et al., 1994).

According to an in-depth study of neck injuries by Olsson et al. (1990) the shape of the crash pulse has a greater influence on the severity of the neck injury than the amount of transferred energy. Recent work by Krafft (1998) shows that the existence of a tow bar as well as being hit by a car with a transversely mounted engine significantly increases the risk of long term disability in rear impacts. It is tempting to believe that, in a rear impact these two factors influence the mean or peak struck car acceleration.

Boström et al. (1996) proposed a new neck injury criterion (NIC) based on a hypothesis of Aldman (1986) and the findings of Svensson (1993). The idea of NIC is to measure the effect of the violence to the neck (normally not life threatening) during the initial retraction phase, phase 1 in Figure 1.

The scientific basis for the NIC-criterion has been further substantiated in recent work, where NIC-values in simulated real-life rear-end collisions have been compared with the actual injury outcome (Boström and Krafft et al., 1997a). The NIC has been found to be sensitive to the seat structure characteristics, the car Δv , and the car crash pulse.

The aim of this paper was to propose and evaluate a new sled test procedure to characterize a car seat from neck injury risk point of view. The design of the test method is based on real-life crash data and research in biomechanics as well as experience from various sled tests and full-scale car tests.

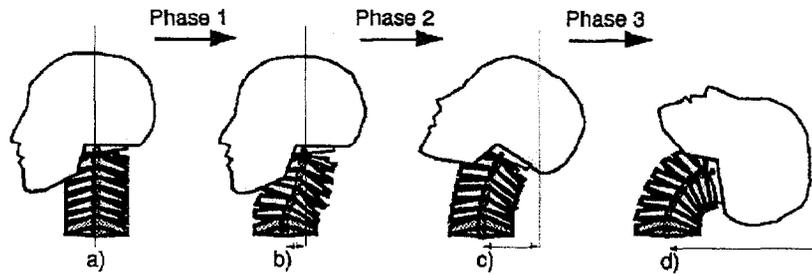


Figure 1 - Schematic view of four parts of the head-neck motion during a rear-end collision: a) initial posture, b) maximum retraction, c) maximum rearward angular velocity of the head is reached, d) hyper extension. The vertical line represents a reference plane in rest. (from Svensson, 1993)

PROPOSED SLED TEST PROCEDURE

The most appropriate crash pulse to use in a sled test with a car seat to simulate a rear impact, should be based on a large set of full scale crash tests with the particular car model. However, the purpose of this study was to evaluate the properties of a seat independently of the corresponding car structure. That is, the ambition was that a seat performing well in this study should perform well in any car regardless of the car structure properties.

In the proposed sled test procedure the seats are exposed to acceleration pulses giving the same Δv but with different acceleration time-history. The difference between the chosen acceleration levels represents the difference between the striking/struck car having a stiff or soft frontal/rear structure, or the difference between a struck car with or without a tow bar. The influence on occupant loading due to such differences have been investigated by Håland et al. (1996) and Boström et al. (1998) by means of full scale crash tests. According to Krafft (1998) these factors indicate a difference in disability risk.

The expected effect of the violence to the neck of a human occupant is measured by the NIC response. The NIC and the tolerance level are defined according to equations 1 - 4.

$$\text{NIC} = a_{\text{relative}} * 0.2 + v_{\text{relative}}^2 \quad [\text{m}^2/\text{s}^2] \quad (1.)$$

calculated at maximal retraction (posture b in Figure 1)

$$a_{\text{relative}} = a_{T1} - a_{C1} \quad [\text{m}/\text{s}^2] \quad (2.)$$

local x-acceleration, T1=lower neck, C1=upper neck

$$v_{\text{relative}} = \text{time integral of } a_{\text{relative}} \quad [\text{m}/\text{s}] \quad (3.)$$

$$\text{Tolerance level of NIC} = 15 \text{ m}^2/\text{s}^2 \quad (4.)$$

In eq. 1, 0.2 [m] is a length parameter. Depending on the biofidelity of the dummy response, these equations may have to be changed, for example by making assumptions about the upper neck (C1) acceleration.

The hypothesis is that a seat which is tolerant to different rear impact crash pulses and has low NIC values, up to maximal retraction, is a good seat with low risk of neck injury.

METHOD

Two standard production seats, seat B ("Bad") and G ("Good"), and an anti whiplash seat, AWS, were tested with a Hybrid III (HIII) 50th percentile male dummy. The AWS has a force controlled yielding of the seat back to give the neck a gentle acceleration until maximum retraction is passed. According to real-life disability data analysed by Krafft (1998), in rear impacts, the seat G car model is much safer than the seat B car model. This agrees with the ranking based on police reported accidents presented by Boström and Krafft et al. (1997a).

The chosen Δv in the sled tests was 15 km/h representing an impact speed of approximately 25 km/h (for equal masses of the target/bullet cars). Two pulses, from now on called the 4g and the 8g pulse, were used in the tests (Figure 2).

The seat back angle was measured by the use of an SAE H-point machine (dummy). It was placed in each seat model and the seat back angle was adjusted so the torso-line was 25 degrees to the vertical. The resulting seat back angle for each seat model was measured and used in the sled tests. The H-point of the HIII was positioned according to the H-point machine and the upper torso was pushed into the seat back with the same force as with the H-point machine. Finally the baseline of the head was placed in a horizontal position.

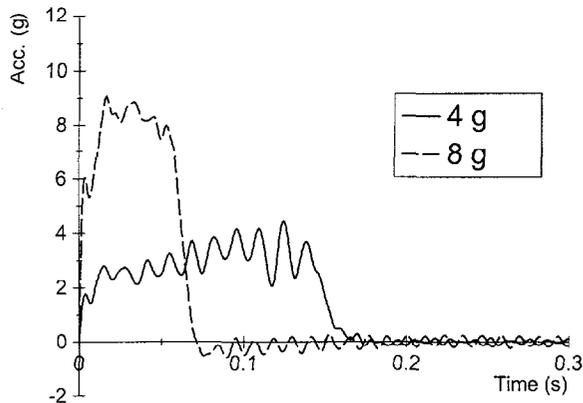


Figure 2 - For the evaluation of the proposed test concept, these pulses were chosen; the 4g and the 8g pulse.

For seat G, the test was repeated with a 5th percentile HIII female dummy seated on a child cushion. The purpose was to evaluate the weight influence on the test results. The reason for the child cushion was to prevent the 5th percentile female dummy from sinking into the seat below the transverse upper seat back beam.

The neck injury criterion (equations 1-4), was configured for the use of the HIII dummy. The neck (as well as the complete spine) of the HIII dummy is far from biofidelic regarding the initial retraction phase. Therefore, the relative acceleration in equation 2 is not applicable for a HIII dummy. On the other hand, the upper neck (C1) acceleration of an unaware human occupant is relatively low until the moment of maximal retraction (eq. 1 and posture b in Figure 1). This is true as long as the head is not accelerated by the head rest during the retraction phase. In order to evaluate the risk of injury/level of protection for a given seat, NIC50 as defined in eq. 5 - 9 was used as a criterion in the current evaluation.

$$\text{NIC50} = a_{\text{lower neck}} * 0.2 + v_{\text{lower neck}}^2 \quad [\text{m}^2/\text{s}^2] \quad (5.)$$

calculated when

$$d_{\text{lower neck}} = 50 \text{ mm} \quad (6.)$$

$$a_{\text{lower neck}} = \text{(local) x-component of the lower neck acc. } [\text{m}/\text{s}^2] \quad (7.)$$

$$v_{\text{lower neck}}, d_{\text{lower neck}} = \text{time integral and double time integral of } a_{\text{lower neck}} \quad (8.)$$

$$\text{Tolerance level, NIC50} = 15 \text{ m}^2/\text{s}^2 \quad (9.)$$

Equations 5-9 are the conformed alternative to eq. 1-4 with the assumption of zero upper neck (C1) acceleration during the initial retraction phase (phase 1 in Figure 1) and the occurrence of maximal retraction after 50 mm of lower neck displacement relative to a non accelerating head.

In addition to NIC50, the upper neck extension moment and shear force (M_y and F_x) were also measured. To evaluate the rebound effect of the seats, the relative upper torso rebound was calculated as follows:

$$\text{Relative upper torso rebound} = \frac{(\text{max. lower neck speed} - \Delta v)}{\Delta v} \quad (10.)$$

If for example the interaction between occupant and seat-back in a rear impact is totally plastic (non-elastic), the maximum neck speed in eq. 10 becomes approximately Δv and the relative upper torso rebound becomes zero. If on the other hand, the interaction is totally elastic, the maximum neck speed becomes approximately $2\Delta v$, with a relative upper torso rebound close to 1 (100%).

RESULTS

The performance of seat G and of seat AWS compared to seat B were quite different. The lower neck acceleration of the HIII in seat B was considerably affected by the difference in pulse, which was not the case for seat G and the seat AWS (Figures 3-5). The resulting NIC50 values for the production seats were in agreement with the disability analysis made by Krafft (1998). It was found that the level of the pulse influenced the NIC value significantly for seat B, but not for seat G (Figure 6). Actually, only the 8g pulse for seat B resulted in NIC values well above the injury threshold of $15 \text{ m}^2/\text{s}^2$.

There was no correlation found between the relative upper torso rebound values and the expected injury outcome (Figure 7). Actually it seemed as seat G was even more elastic than seat B.

For all tests, the traditional neck criteria, upper neck extension moment and shear force, were well below the AIS2+ tolerance levels (57 Nm/1100 N) proposed by Backaitis and Mertz (1994) (Figures 8-9). However, for seats G and B, the shear force (F_x) values were lower in the 4g pulse tests compared to the 8g pulse tests. For the 8g pulse, the seat B F_x value was higher than the corresponding values for seat G and seat AWS.

The results of the test with the elevated HIII 5th percentile female dummy were comparable with the results with the HIII 50th percentile male dummy. There was no substantial difference regarding the NIC response for the two pulses (Figure 10). The lighter dummy experienced, however, slightly higher NIC50 values.

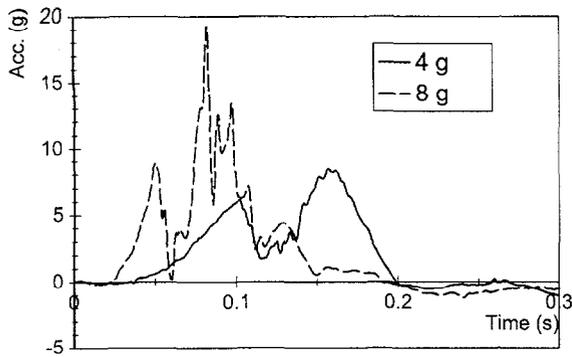


Figure 3 - Lower neck acceleration for seat B for the two crash pulses.

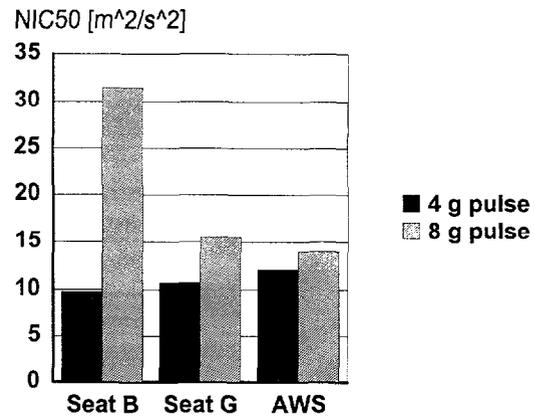


Figure 6 - NIC50 values for the HIII 50th percentile male dummy for the two pulses for seat B, G and AWS. The tolerance level is $15 \text{ m}^2/\text{s}^2$.

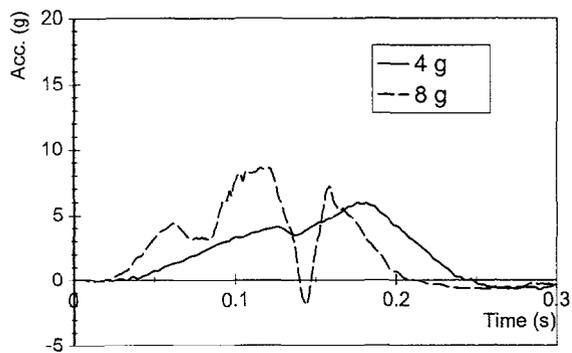


Figure 4 - Lower neck acceleration for seat G for the two crash pulses.

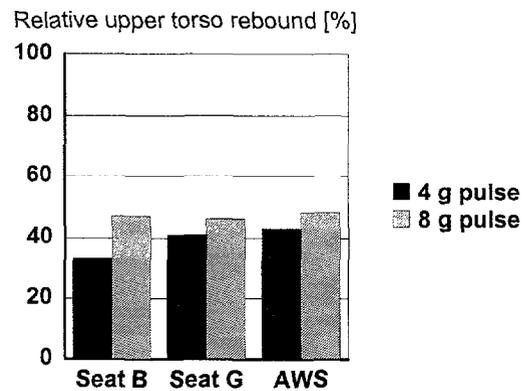


Figure 7 - Relative upper torso rebound, defined in eq. 10, for the HIII 50th percentile male dummy for the two pulses for seat B, G and AWS.

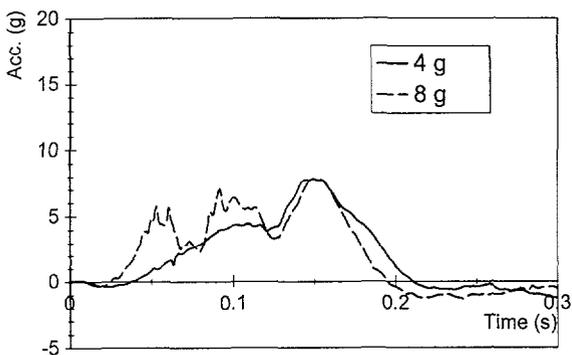


Figure 5 - Lower neck acceleration for seat AWS for the two crash pulses.

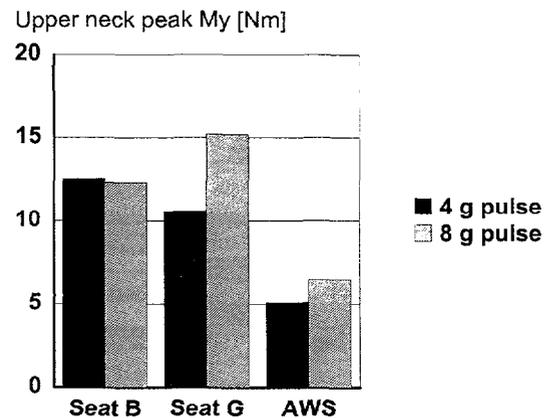


Figure 8 - Peak upper neck torque, M_y , for the HIII 50th percentile male dummy for the two pulses for seat B, G and AWS.

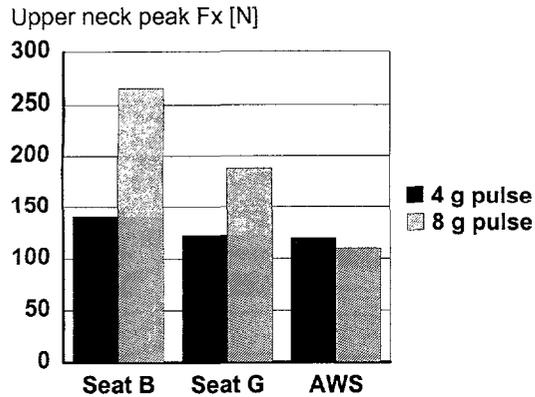


Figure 9 - Peak upper neck shear force, F_x , for the HIII 50th percentile male dummy for the two pulses for seat B, G and AWS.

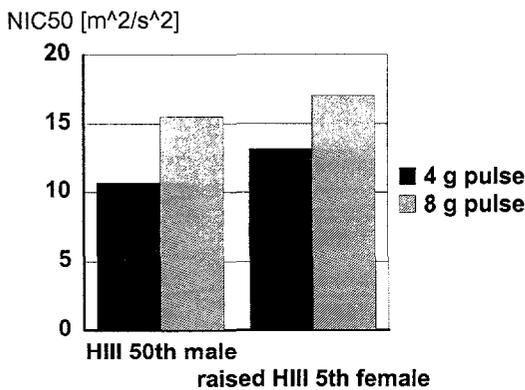


Figure 10 - NIC50 values for the HIII 50th percentile male dummy compared to the values for the raised HIII 5th percentile female dummy for the two pulses for seat G.

DISCUSSION

The pulses (the 4g and 8g pulses) and the Δv (15 km/h) used in this study were chosen on the basis of full scale rear impacts, where the impact speed was 25 km/h. If it is determined that the 8g pulse is not an accurate representation of an average injurious impact, the level of pulse and/or the Δv will have to be changed in the sled test procedure.

The explanation for the lower NIC50 values and the insensitivity to the shape of the acceleration pulse for seat G and seat AWS is clearly the "softer" performance indicated by the lower neck accelerations shown in Figure 3-5. In addition, the "softer" performance of seat G and seat AWS also resulted in decreased upper neck shear forces. This is in agreement with the analysis of a series of

sled tests with a HIII dummy equipped with a Rear Impact Dummy (RID) neck developed by Svensson and Lövsund (1992), where the *initial* upper neck torque and shear force maxima were shown to correlate with the NIC values (Boström et al., 1997b). However, in contrast to the NIC values, for all sled tests in this study as well as in the study by Boström et al. (1997b), the peak upper neck moment and shear force were well below the tolerance levels (57 Nm/1100 N; Backaitis and Mertz, 1994). In this study only the NIC50 values, in agreement with disability data, prove seat B being worse than seat G.

The major limitations of the seat test procedure (performed) seem to be the disregard of the seat geometry, the restriction to low velocity and the focus on AIS 1 injuries. The motivation for a test with these limitations is the fact that head rests of car seats have a low efficiency (Nygren 1984, Brault et al. 1998) and that high velocity rear impacts and AIS2+ injuries are rare (Otte et al., 1997). The proposed sled test procedure seems to evaluate the risk of neck injury and the level of protection in an elementary way. That is, the test is able to discriminate between cars (seats) with rather different disability rankings. In order to evaluate a seat more precisely, taking the seat geometry into account, a dummy with more human like properties regarding spinal motion is needed. Such a dummy is under development in Sweden and will be presented later (Davidsson et al., 1998).

The use of a dummy representing an average female instead of an average male would be more appropriate since females are at higher risk (Krafft et al., 1996). In this study, the 5th percentile female dummy was elevated with a cushion in order to simulate a light (compared to an average) female with an average seating height. As a result, the NIC values were slightly higher. However, no *more* information was gained. It appears, on the basis of this limited dummy weight study, that a seat that accelerates a dummy representing an average male in a gentle way (low NIC values), regardless of the acceleration profile, will accelerate a 50th percentile female dummy in a similar manner.

CONCLUSION

The proposed seat test procedure evaluates the risk of neck injury and level of protection in typical low speed rear impacts. It includes two different acceleration pulses and uses the NIC as the main injury risk indicator. To conclude the findings of this study:

- The proposed sled test procedure with the HIII dummy appears to be relevant for an elementary evaluation of car seats regarding the risk of neck injury in low velocity rear-end impacts.
- Seats (seat backs) with low yielding limit are tolerant to different rear impact crash pulses and have low NIC50 values.
- A gentle neck acceleration, until maximal neck retraction is passed (posture b in Figure 1), could prevent neck injuries with a risk of permanent disability from occurring, as the NIC50 value would be below the tolerance level.

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